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Advanced Space Program Studies Overall Executive Summary

Prepared by

Advanced Mission Analysis Directorate
Advanced Orbital Systems Division

March 1976

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D. C.

Contract No. NASW-2727

Systems Engineering Operations

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ADVANCED SPACE PROGRAM STUDIES
Overall Executive Summary

S. M. Tennant
General Manager
Advanced Orbital Systems Division

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FIGURES

1. INTRODUCTION

This report is an Overall Executive Summary of work accomplished from 1 September 1974 through 27 February 1976 on the seven Advanced Space Program Studies covered by NASA Contract NASW-2747. Table 1-1 lists the studies, their funding, and The Aerospace Corporation MTS deliveries.

Table 1-1. Advanced Space Program Studies

Study	Title	Funding	MTS Man Months
2.1	Manned Systems Utilization Analysis	$351,000	57.7
2.2	STS Users Study	200,000	31.8
2.3	Vehicle Cost/Performance Analysis	100,000	18.1
2.4	Standardization and Program Effect Analysis	258,700	39.5
2.5	Study of the Commonality of Space Vehicle Applications to Future National Needs	425,000	58.5
2.6	STS Spin Stabilized Upper Stage (SSUS) Study	150,000	25.7
2.7	Technology Assessment and Forecast	21,000	3.3

The objectives of these studies were to provide NASA with multidisciplined advanced planning studies that involved space operations and the associated system elements (including man), identification of potential low cost system techniques, vehicle design, cost synthesis techniques, DoD technology forecasting, and the development of near- and far-term space initiatives with emphasis on domestic and military use commonality. All of the studies involved consideration of both NASA and DoD requirements and planning data. Studies 2.1 through 2.5 were covered in the

Statement of Work. Studies 2.6 and 2.7 were added to the contract in February and June 1975, respectively.

The Advanced Space Program Studies performed by The Aerospace Corporation since FY 1970 have been for the NASA Office of Manned Space Flight. The support base, however, was broadened in FY 1975 to include the Low Cost Systems Office (Study 2.4) and the Office of Aeronautics and Space Technology (Study 2.7).

Every attempt was made to integrate the studies, where feasible, and in particular to utilize the data from individual studies to the extent possible in the other studies. An example is Study 2.3 - "Vehicle Cost/Performance Analysis" and Study 2.4 - "Standardization and Program Effects Analysis." The computerized technique developed in Study 2.3, which allowed the design and cost synthesis of an unmanned payload based upon mission requirements, was used to configure and cost the "New Starts" in Study 2.4 and provide quantification for the use of standarized hardware.

A key effort that has received vast exposure was Study 2.5 - "The Study of the Commonality of Space Vehicle Application to Future National Needs." This effort identified more than 100 new and highly innovative space systems for the 1980 - 2000 time period that offer promising utility and commonality to both the domestic and military sectors.

An effort that was initiated approximately midway into FY 1975 was Study 2.6 - "Spin Stabilized Upper Stage" (SSUS). This effort was directed at investigating the utility of spinning solid upper stages deployed from the orbiter to perform a variety of upper stage NASA payload missions. This approach was found to be very attractive for Delta (up to 1000 lb on orbit) and Atlas Centaur (up to 2100 lb on orbit) class payloads.

In all studies, the unique ability of The Aerospace Corporation to focus on DoD planning and incorporate these data in the NASA studies was exercised.

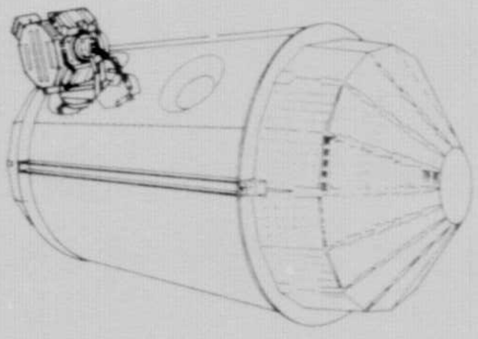
2. MANNED SYSTEMS UTILIZATION ANALYSIS (STUDY 2.1)

The Skylab/ATM (Apollo Telescope Mount) experience has shown that active manned support, at least for complex scientific instruments, is vital to the achievement of mission objectives. Many of the ATM instruments would have fallen far short of their scientific objectives had this direct form of support not been available. Manned maintenance, therefore, with proper spares provisioning and a few basic tools, is seen as a unique element in the planning for future space operations.

The objective of this effort was to relate this capability for sustaining scientific instruments in orbit to alternate measures for achieving comparable system availability. This was achieved two ways. First, by comparing historical evidence of similar scientific instruments relative to anomalous occurrence and the subsequent actions taken to sustain operations. Second, a comparison of manned maintenance versus redundancy of design was made for the Skylab S-056 X-ray telescope to achieve comparible availabilities. This provided a foundation for extrapolating to future space operations relative to the preferred mode of operation. The results of this effort are summarized in the following sections.

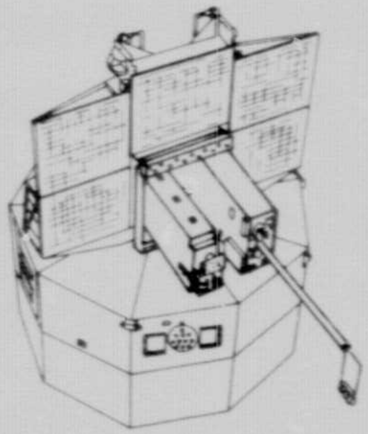
2.1 APPROACH

The foundation for the research into anomalous occurrences was developed by examining the historical results of three similar experiments programs. These were the OV1 series of automated spacecraft developed by the USAF, SAMSO organization; the OSO-7 automated spacecraft developed by NASA, GSFC; and the Skylab S-056 X-ray telescope experiment in the ATM, as shown in Figure 2-1. Each program was similar in its objectives and represented increasing levels of complexity to accomplish the mission objectives -- the gathering of X-ray spectral data. Each pro-



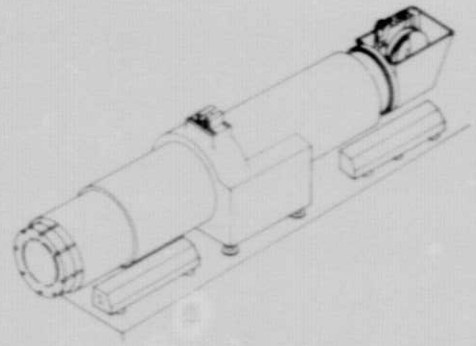
OV1-10, -17

Instrument type:	Crystal spectrometer, proportional counter
Area of sun covered:	Full disk
Resolution:	None (emission from whole sun)
Data format:	Spectral scans, total flux
Physical:	12 x 12 x 14 inch, 18 lbs
Mount:	Bi-axial sun centered pointer, 20 arc-sec stability



OSO-7

Instrument type:	Grating spectrometer, proportional counter, Hα polarimeter
Area of sun covered:	Full disk in raster scan
Resolution:	10 x 20 arc-sec
Data format:	Spectral scans, total flux, Hα, polarization
Physical:	7 x 14 x 50 inch, 50 lbs
Mount:	Bi-axial raster, sun-centered pointer, 1 arc-sec stability



S-056

Instrument type:	Filtergraph, proportional counter
Area of sun covered:	Full disk
Resolution:	2 arc-sec in pictures, none for counter
Data format:	Photographs, total flux
Physical:	23 x 24 x 105 inch, 354 lbs

Figure 2-1. Basic Experiment Characteristics

gram had unique failure modes and in each case, to some degree, fell short of accomplishing the total mission objectives.

A second effort addressed special features in terms of weight, volume, and reliability associated with designing for space maintenance. This was achieved by reconfiguring the S-056 X-ray telescope for maintenance and using these data to extrapolate to other ATM experiments. The estimated reliability characteristics were then examined to determine the benefits of repair operations, as well as when redundancy should be employed to achieve comparable availabilities on orbit.

2.2 MAINTENANCE ASSESSMENT

Several empirical factors were developed to express the value of maintenance action, either through remote command or by direct action on the part of a crew man. These factors provided a relative measure to the value improvement by repair action as a function of the complexity of the instrument involved. Historical data formed the basis of this assessment process. As an example, the OV1 had a telemetry interference problem, the OSO-7 was oriented incorrectly and the S-056 had high friction loads in the film drive mechanism.

The results of this effort indicated that without corrective action either by remote command or in the case of the S-056, by direct manned contact, the instruments would have failed early in their operational periods. Further, as the complexity of the design increased, the need for direct maintenance (by a flight crew member) substantially increased. As evidenced with the S-056 X-ray telescope, (as well as all the ATM experiments) numerous repair actions were required during the course of the mission. All of this occurred in spite of the fact that extensive ground testing was performed before the equipment was committed to orbit.

The conclusions drawn, therefore, were:

1. Scientific instruments exhibit a trend toward increased complexity and cost to fulfill expanding objectives.

2. Scientific instruments, in general, incorporate very little redundancy and, in fact, because of the uniqueness of the instruments' redundancy, seldom provide a viable option (optics, beam splitters, etc.).

3. In the future, direct manned maintenance can offer an effective means for achieving a high instrument availability for complex scientific experiments operating for extensive periods of time.

4 The additional weight, volume, and cost impact associated with initially designing for manned interaction is minimal for instruments of this type relative to the improved operational potential.

Further evidence of the advantage of this design approach is shown in Figure 2-2. This figure provides a comparison of the weight impact associated with the achievement of various levels of operational availability for the S-056 X-ray telescope. In both cases, the results have been optimized to provide the greatest improvement in availability fot the lowest incremental weight increase. An initial penalty occurs for the repair option due to provisions for access to all key components of the instrument (shutter drive motors, filters, etc.). However, once this has been accomplished, and spare components made available, it is seen that a substantial improvement in availability can be achieved with little additional penalty. This occurs because the components themselves are relatively small and interchangeable (motors, power supplies).

Although these characteristics may vary with other scientific instruments, the trend shown should be applicable to a wide range of optical sensors. A relatively high availability over a long operational period is desired. The potential to achieve this availability through the use of redun-

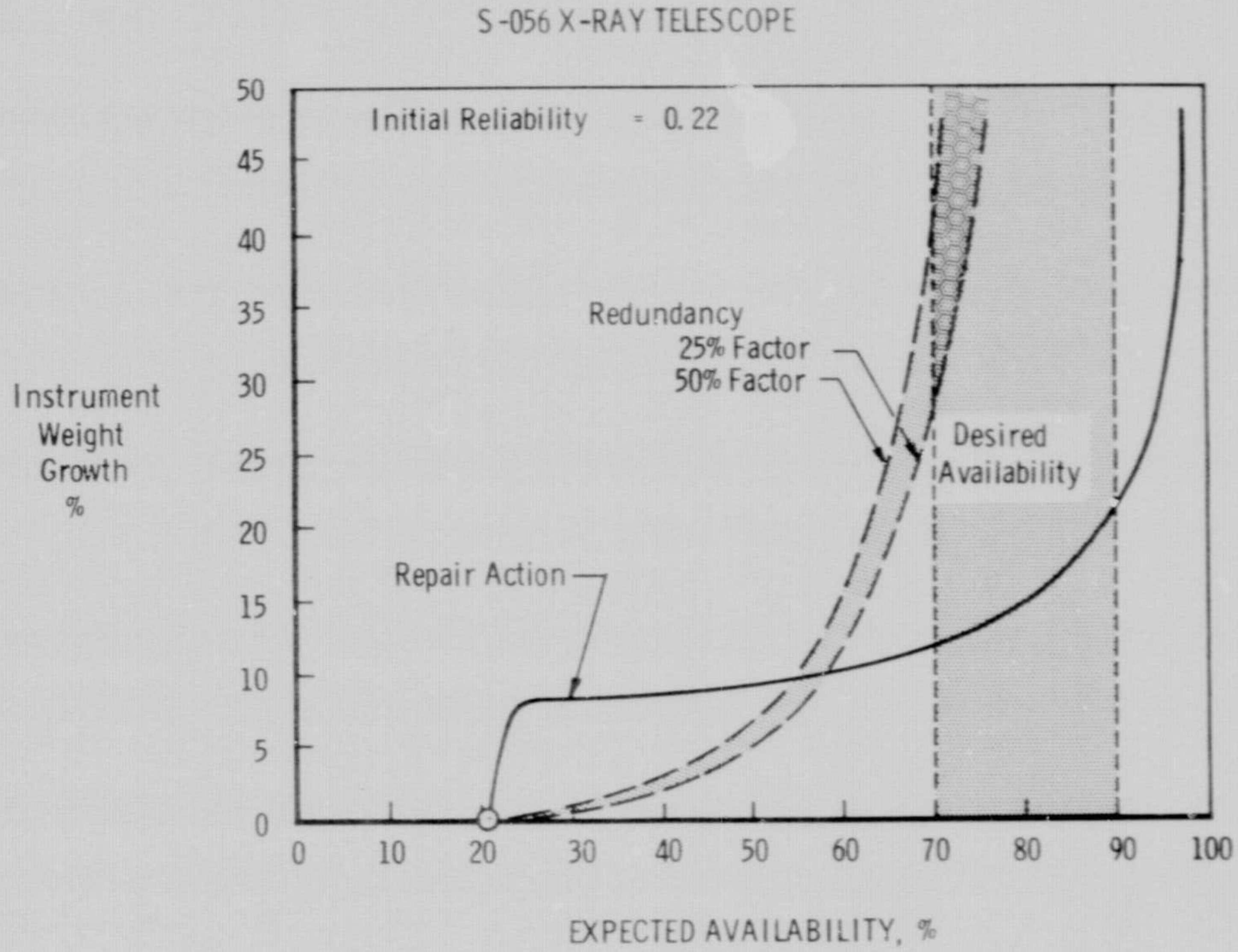


Figure 2-2. Redundancy versus Repair for S-056 (Initial Rel. =0.22)

dancy has a practical limit that may preclude achieving the mission goals. In practice, a combination of both concepts should be employed: utilize redundancy where it can be employed effectively, but do not preclude manned maintenance of all critical areas of importance.

The S-056 X-ray telescope had numerous single-point failures that could have substantially reduced the mission effectiveness had they occurred. However, the anomalies that occurred would not normally be exposed by any reliability analysis anyway.

Hence, it is concluded that the success of the mission was due principally to the fact that man was available for maintenance of those unpredictable anomalies that inherently occur in any complex system. Man was that unique element which provided the flexibility of action to sustain a system that otherwise would have terminated within the first few weeks of operation.

This lesson should not go unheeded as plans for future missions evolve. Complex scientific instruments, whether free-flyers or Spacelab payloads should not preclude manned interaction as the most effective means of achieving high system availabilities.

3. STS USERS STUDY
(STUDY 2.3)

The STS User Study included:

a. The STS User Plan (User Data Requirements) Study

b. The Ancillary Equipment Study.

The objective of the STS User Data Requirements Study was to identify STS user required data not being furnished and describe them. In addition, the NASA STS User Handbook effort was supported by this STS User Plan Study.

In order to define and develop Multi-Mission Support Equipment (MMSE) for the STS, NASA needed to understand which support equipments under consideration were potentially useful for DoD STS payloads. This could result in a cost savings for both agencies. In Part 2 of the STS User Study, the ancillary equipment needs for DoD payloads were examined. It appeared that many of the NASA MMSE corresponded to the types of equipment needed by DoD and thus considerable savings were possible. Fifteen on-line MMSE were potentially applicable to one or more of the DoD payloads in the near term.

3.1 STS USER PLAN (USER DATA REQUIREMENTS) STUDY

3.1.1 Objectives

The objectives of the STS User Plan (User Data Requirements) Study were to:

a. Prepare an overall estimate of data and planning requirements needed by the STS user

b. Determine where the NASA and USAF studies related to STS users fit into the estimated Matrix of planning requirements

c. Provide NASA with the contractors' estimates of additional user required data not currently covered by study activity which, if carried out, would satisfy the requirements.

3.1.2 Approach

On the basis of the information on NASA and DoD payload projects, a list of STS user data requirements were made. The requirements included data shown to be needed for past or current payload projects. The data requirements were identified with the project phase for which each was required. STS payload study data were also used to determine payload data requirements. In addition, user data requirements which might not be evident from the documentation were generated by payload specialists.

The user data requirements list was related through a matrix format to a typical payload project activity by program phase. The full matrix listing the user data requirements is 39 pages and is presented in the STS Users Study (Study 2.2) Final Report, Volume II: STS User Plan (User Data Requirements) Study, Aerospace Report No. ATR-76(7362)-1, dated 1 November 1975. A condensed example is shown in Table 3-1. The data requirements are listed in the lefthand column and payload program phases are listed across the top of the page. Pre-Phase A and Phase A are conceptual study phases; while Phase B is a system definition phase. Phases C and D are the Design and Development Phases. These phases represent typical steps which a user's payload project may go through. Where ① appears in a column, the data are required in order to carry out a normal study in that phase of payload activity. Where a ② appears, it denotes that it is desirable to have the inforn. 'on or data available for that phase of the study, but the study could normally be carried out using assumed or estimated data. The numbers in the matrix (uncircled) are the number of documents reviewed which contain data pertinent to the area.

Table 3-1. Condensed Example of Page From User Data Requirements for Matrix

PAYLOAD/SHUTTLE INTEGRATED FLIGHT
ON-LINE DATA REQUIRED RELATIVE TO THE STS SYSTEM BY STS PAYLOAD PROJECTS
DATA REQUIRED, NUMBER OF DOCUMENTS APPLICABLE, AND MISSING DATA (M)

Data Requirements For: / Payload Program Phases	Pre-Phase A	Phase A	Phase B	Phase C/D
Shuttle Performance & Mission Analysis Data	① 14	① 17	① 12 M	① 6 M
Structural Support and Physical Constraints		② 7	① 5	① 2
Shuttle Attitude and Position Accuracy		① 4	① 5	① -
Shuttle Environment and Contamination	② 10	① 10	① 8 $\boxed{M}$	① 5 $\boxed{M}$
EM Compatibility/EM Interference			① 2	① 2
Loads		② 5	① 6 $\boxed{M}$	① 3 $\boxed{M}$
Sequence of Events	② 2	① 2	① 1	① -
User Charges		② 1	① 1	① 1
Orbiter Maneuvers and Docking		① 6	① 5	① 7
User-Furnished Propulsion		② -	① - M	① - M
Common Support Equipment*		② 1	① 1	① -
Orbiter-Furnished Services, Panels		① 14	① 13	① 4 $\boxed{M}$
Safety		② 5	① 3	① 2
Spacelab Capability	② 2	① 2	① 1 $\boxed{M}$	① - $\boxed{M}$
Abort Provisions				① - M
Crew (PS, MS) Functions	② 8	① 8	① 5	① 1
Flight Scheduling and Manifests	② 5	① $\boxed{M}$ 7	① 2 $\boxed{M}$	① 1 $\boxed{M}$

* Multi-Mission Support Equipment (MMSE), kits and general purpose GSE.

NOTES:
- ① Designates that at least some of the data in this category is required for this phase
- ② Designates that it is desirable to have at least some of the data in this category for this phase
- M User required data is missing
- $\boxed{M}$ User required data is missing and a data requirements statement has been written

The completed User Data Requirements Matrix was inspected to determine where data were missing or inadequate. In Table 3-1 the notation "M" designates areas where data are missing. Where appropriate, statements of user data requirements were prepared (in RTOP format) and transmitted to NASA and these are so designated with a $\boxed{M}$.

3.1.3 Results

In this study it was found that the STS user required information related to flight scheduling and flight manifests that was not available to him. It was also found that data on payload dynamic loads (during ascent and return) and load alteration approaches were not available. Recent technical studies simulating the dynamic payload/orbiter combination have shown that dynamic loads during landing can be as high as 5 to 9 gs. These loading conditions are critical to the design of some elements of the payload structure.

The STS user has the option to use orbiter power, communications, cooling, and other services, as well as orbiter attachments, the remote manipulator, and attitude and navigation handoff data. Each of the services is supplied through orbiter and orbiter/payload interface equipment. The user needs failure mode, effects, and frequency of occurrence data covering each of the equipments.

During the study it was found that the acoustic environment to which the payload would be subjected at liftoff was being predicted on the basis of analytical studies and model testing. The uncertainty in the predicted acoustic environment was relatively large and it was recommended that a 3-sigma, worst-case type environment prediction be made for use by payloads interested in a low-risk development program.

Statements of user data requirements were also prepared in several additional areas. Approaches to documenting the data required by

STS users were developed. User document outlines are presented in the Study 2.2 Final Report, Volume II.

3.2 ANCILLARY EQUIPMENT STUDY

3.2.1 Objective

The objective of the STS Ancillary Equipment Study was to describe, from NASA's point of view, the potential for common usage of Multi-Mission Support Equipment (MMSE) by DoD in addition to NASA users.

3.2.2 Approach

The NASA Multi-Mission Support Equipment (MMSE) are described in the Martin Marietta catalogs for launch site and airborne (or on-line) MMSE. The catalogs, modifications in the catalog descriptions, and description of items not in the catalogs were furnished to this study by MSFC and KSC.

Most of the launch site MMSE could be studied for applicability to DoD without the detailed payload data required for the airborne MMSE. DoD airborne ancillary equipment needs were extracted from the information and data from the DoD STS Payload Interface Studies.

The DoD ancillary equipment needs were then compared to the MMSE list to identify candidate MMSE for application to the DoD mission model. Thirty-one of the 35 items of airborne MMSE were identified as candidates for DoD ancillary equipment.

3.2.3 Results

In the near-term STS era (through 1985), 15 on-line MMSE items were found to have one or more potential users among the DoD payload projects. These potentially common NASA/DoD equipments are in the following categories:

a. The IUS/payload structural interface

b. Mounts for piggyback payloads in the orbiter bay

c. Radioisotope thermoelectric generator cooling equipment

d. Orbiter/payload servicing cable (electrical)

e. Payload shroud

f. Payload purging equipment

Thirteen launch site MMSE items were found to have potential users in the DoD mission model.

Several equipment items were recommended for addition to the NASA MMSE candidate list as another result of the Ancillary Equipment Study.

4. VEHICLE COST/PERFORMANCE ANALYSIS (STUDY 2.3)

As the space program matures, greater emphasis will be placed on improving the ability to predict the effect of program requirements on cost and schedules. Cost estimating techniques that give greater insight earlier in the program cycle are required. As a step in this direction, this study was initiated to identify and quantify the interrelationships between and within the performance, safety, cost, and schedule parameters for unmanned, automated payload programs. These data would then be used in support of the over-all NASA effort to generate program models and methodology that would provide the needed insight into the effect of changes in specific functional requirements (performance and safety) on the total vehicle program (cost and schedule).

Previous cost modeling approaches fall into one of two basic categories: "bottom-up" or "top-down." The "bottom-up" approach, which is tied to the development of a specific system, depends on detailed estimates of tasks, material costs, manpower requirements, and schedules. The total cost estimate is then obtained by summing the individual costs.

"Top-down" models use CER (cost estimating relationship) approaches to estimate the cost of a specific system. In these models, the CERs are related to distinct parameters such as weight, (see Figure 4-1). The deficiency of the CERs lies in the fact that, although they identify cost drivers, they do not model why and how the costs are driven by the parameters.

Since CERs have not been completely successful in meeting the prime criterion of determining sensitivity of cost to changes in the program requirements, top-down approaches were judged unacceptable for a cost/

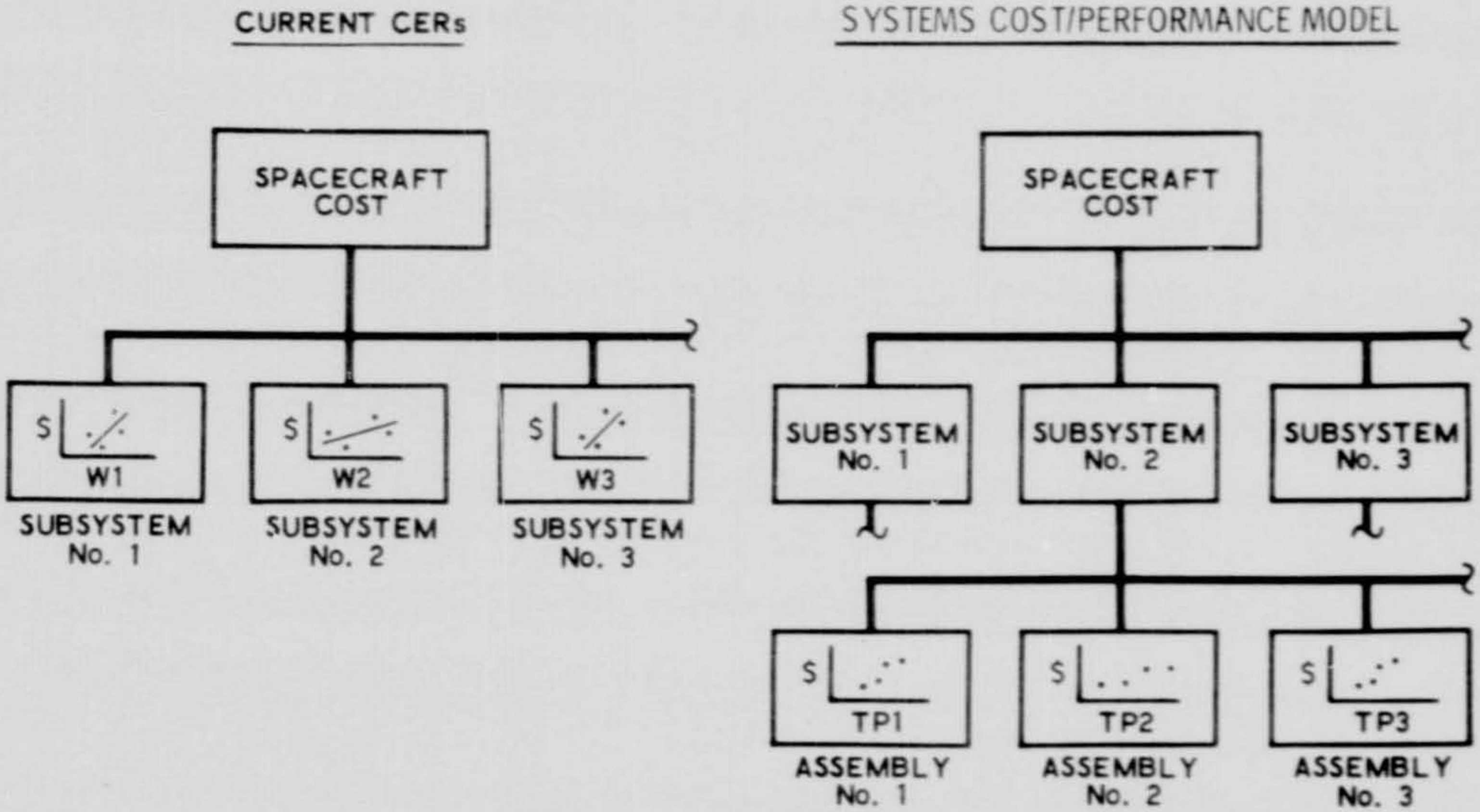


Figure 4-1. Cost Models

performance model. Hence, it was thought that a model oriented from the bottom-up could lead to fulfillment of this criterion. The bottom-up approach would allow the cost estimates to be based directly on technical performance (see Figure 4-1) and design complexity.

4.1 GENERAL

The general concept of the Systems Cost/Performance Model is illustrated in Figure 4-2. The user of the Cost/Performance Model must supply certain program data that would normally include the payload performance requirements as well as general information necessary to select a payload design. The technical portion of the model consists of a two-step process: the first step is to select subsystem configurations that are acceptable to the user, and the second step is to select equipment from a data base to mechanize the subsystem configuration. The reliability portion of the model adds redundancy to the design so that the reliability requirements are met. The resulting output of the technical model is a number of payload designs that meet or exceed the input requirements. The acceptable designs are specified down to the subsystem component (assembly) level. The cost and schedule required to design, build, and operate each payload are estimated by summing up the individual cost and schedule allocations based on each end item assembly specified as part of the particular design.

4.2 SIGNIFICANT RESULTS

The major accomplishment of the effort was the development of a model possessing the ability to design unmanned, automated payloads. Subsystem, safety, cost, and schedule models were developed. Each of these models interfaced properly with the remainder of the model. The model was self-sufficient in that no intermediate steps needed to be performed by the user. The Systems Cost/Performance Model has been

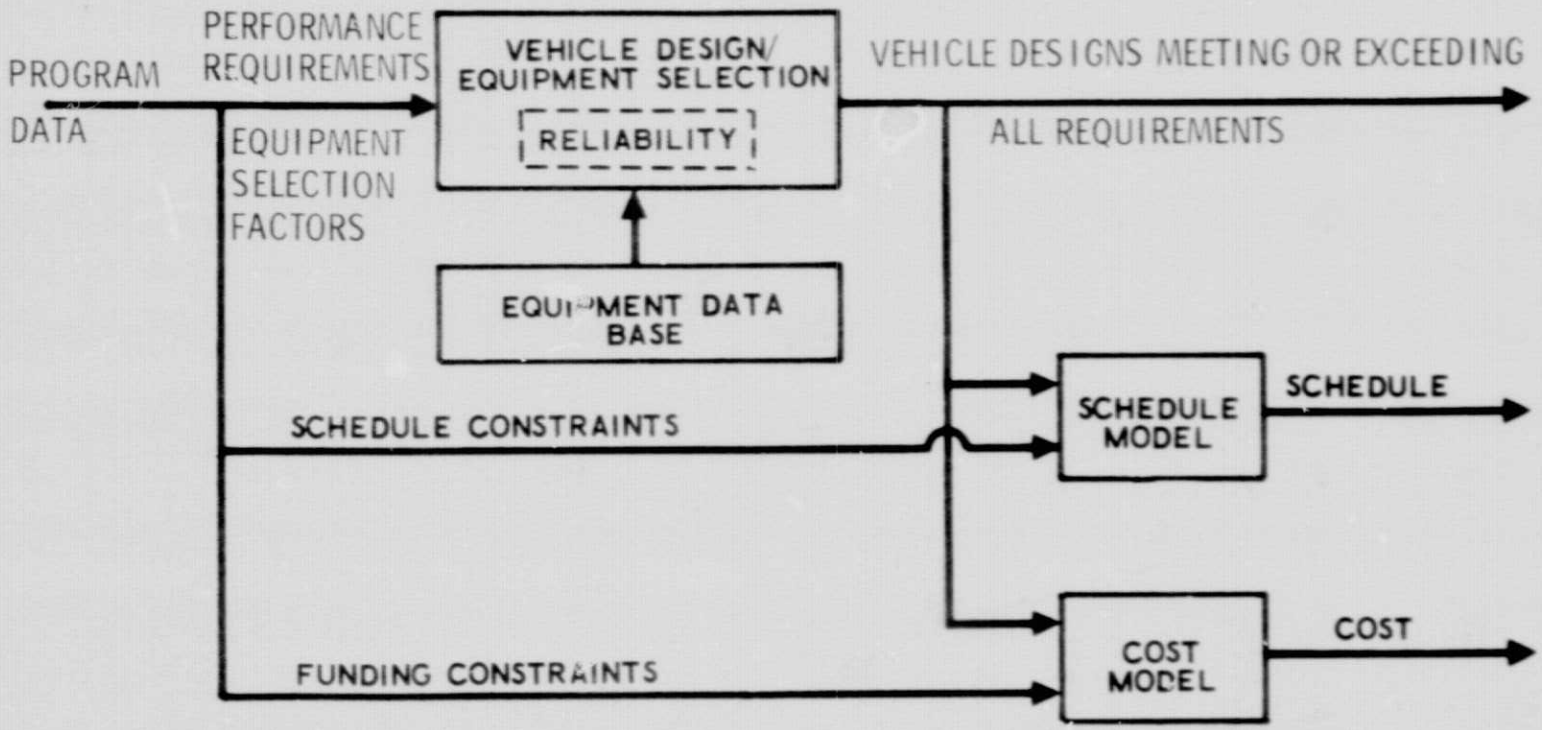


Figure 4-2. Systems Cost/Performance Model

implemented as a digital computer program and is operational on The Aerospace Corporation's CDC 7600 and IBM 370-155 computers and on MSFC's Univac 1108 computer.

Three test cases were used to check the Cost/Performance Model and the operation of the computer program. The three test cases were:

a. Defense Satellite Communication System (DSCS-II)
b. Earth Resources Technology Satellite (ERTS-A)
c. Orbiting Solar Observatory (OSO-I)

The results of these three test cases indicated that the current Model was capable of estimating spacecraft program costs with reasonable accuracy. The error in the total cost estimate (using preliminary CERs) was less than 24% relative to the actual DSCS-II costs.

Generally speaking, the Cost/Performance Model should exceed the performance of "top-down" models. The model uses a "bottom-up" approach and, therefore, designs the payload at the assembly level. Greater accuracy is achieved by the very nature of the more detailed design. This accuracy will be reflected in the cost and schedule model estimates. A second attribute of the Cost/Performance Model is the completeness of the design specified. Pieces of equipment are not forgotten, and redundancy is automatically included in the specified design. In addition, the impact of all subsystem interfaces and interactions is properly modeled. The net result is a payload design that is as accurate and complete as one from a Pre-Phase A study and which is available to the Cost/Performance Computer Program user immediately.

Because of the detailed nature of the model, the uses of the System Cost/Performance Model exceed that for "top-down" models. The following uses of the model were suggested:

a. Pre-Phase A Planning

1. Structure realistic programs in terms of matching performance, budgets, and schedule.
2. Perform mission model analyses.
3. Assess the potential savings from use of standardized equipment.

b. Preliminary Design

1. Establish specific payload designs and the related costs.
2. Develop standardized designs using a data base consisting of standardized equipment.
3. Identify low cost designs using a data base consisting of off-the-shelf equipment.
4. Perform modularity studies by modifying the model to assign equipment to modules.

c. Program Management

1. Assess contractor cost and schedule estimates.
2. Determine the sensitivity of design, costs, and schedules to changes in requirements.
3. Perform trade studies to identify optimal designs.

The model ca readily be expanded in its scope to perform many other studies as well. The model will become a more versatile tool in terms of preliminary program planning and in actual program management as it becomes more fully developed.

4.3 SUGGESTED RESEARCH AND ADDITIONAL EFFORT

It was recommended that the model be thoroughly verified and validated. The most useful validation procedure would be to use the model on test cases selected from historical programs, operational programs, and new starts. Historical and current programs provide the most accurate data with which to validate the model. New start programs will test the

applicability of the model as a preliminary planning tool. It was further recommended that the capability of the model to predict space vehicle interrelationships be tested and that the potential of the model to assist in programmatic change control such as configuration management be evaluated by a user review.

It should be clear the additional cost, schedule, and technical data must be collected and processed. The focus of the current study was on developing a model rather than augmenting a data base. Only after the model was successfully developed and proven as a useful tool could data collection be justified at such a detailed level. On the other hand, lack of adequate data hindered the development of the current model. The cost model must be considered preliminary, and the schedule model cannot be considered operational until sufficient data have been collected to improve and validate the model. Hence, widespread use of the Systems Cost/Performance Model depends entirely on the collection of performance, safety, cost, and schedule data at the subsystem component (assembly) level.

5. STANDARDIZATION AND PROGRAM EFFECT ANALYSIS (STUDY 2.4)

Many current satellites in development that employ expendable boosters are emphasizing the use of flight-qualified and standardized components. Moreover, the use of standardization becomes more practical when the satellites are designed for the STS era, since the transportation interface will be common and the environment will be the same for each satellite mission. A study was conducted to quantify the benefit of using developed hardware if a large number of flight-qualified components and standard equipments are available for new starts. In addition to the study of reducing hardware costs, an analysis to examine the program practices to control costs was also conducted. A spacecraft project that incorporated the design-to-cost philosophy was examined for this study on program practices.

5.1 OBJECTIVE

The overall study objective was to assist NASA in the development of potential cost savings for the satellite programs starting in 1976 and beyond. The primary tasks were: (1) catalog a large number of components from current NASA and DoD satellites, and (2) quantify the new start savings if the components listed in the catalog and the NASA Standard Equipment are used. The secondary task was to review the program practices used in a spacecraft project that actually used design-to-cost philosophy.

5.2 APPROACH

The cataloging task compiled the programmatic information, key technical characteristics, and cost data on available flight-qualified components from 17 current DoD and NASA satellites. Over 400 components were cataloged with the type of information to make candidate selections on

functional and cost basis.

The new start task applied the catalog to five new starts that are shown in Figure 5-1. The spacecraft and subsystem characteristics of the new starts were developed by inputting the mission and system characteristics into a computer model known as the Spacecraft Design and Cost Model (SDCM) originally developed under NASA funding by Aerospace in Study 2.3 during the period of FY 73 to FY 75, and then extended with company funds. The subsystem specialists used the SDCM output to develop the component functional requirements that formed the technical basis for component selection. The set of candidate components was then inputted into the cost portion of the SDCM for the cost estimates. This technique which computes spacecraft costs by component generates data to cost evaluate alternate configurations where only components are varied.

The design-to-cost task examined the program practices of the Earth Limb Measurements Spacecraft project. The data on program practices were obtained by discussions with key SAMSO, Aerospace and Grumman project personnel, and reviewing contractual and system performance reports. Practices and areas that reduced and increased costs were identified.

5.3 CONCLUSIONS

The study has determined that significant program savings can be achieved by using flight-qualified hardware. New start spacecraft can be configured with major portions of the housekeeping subsystems using developed components from DoD and NASA projects. Along with the use of components, the amount of component modifications for integrating the unit into new starts was found to be relatively low.

The total cost reduction by extensive use of flight-qualified components was estimated to be in excess of $100 M over the "business-as-

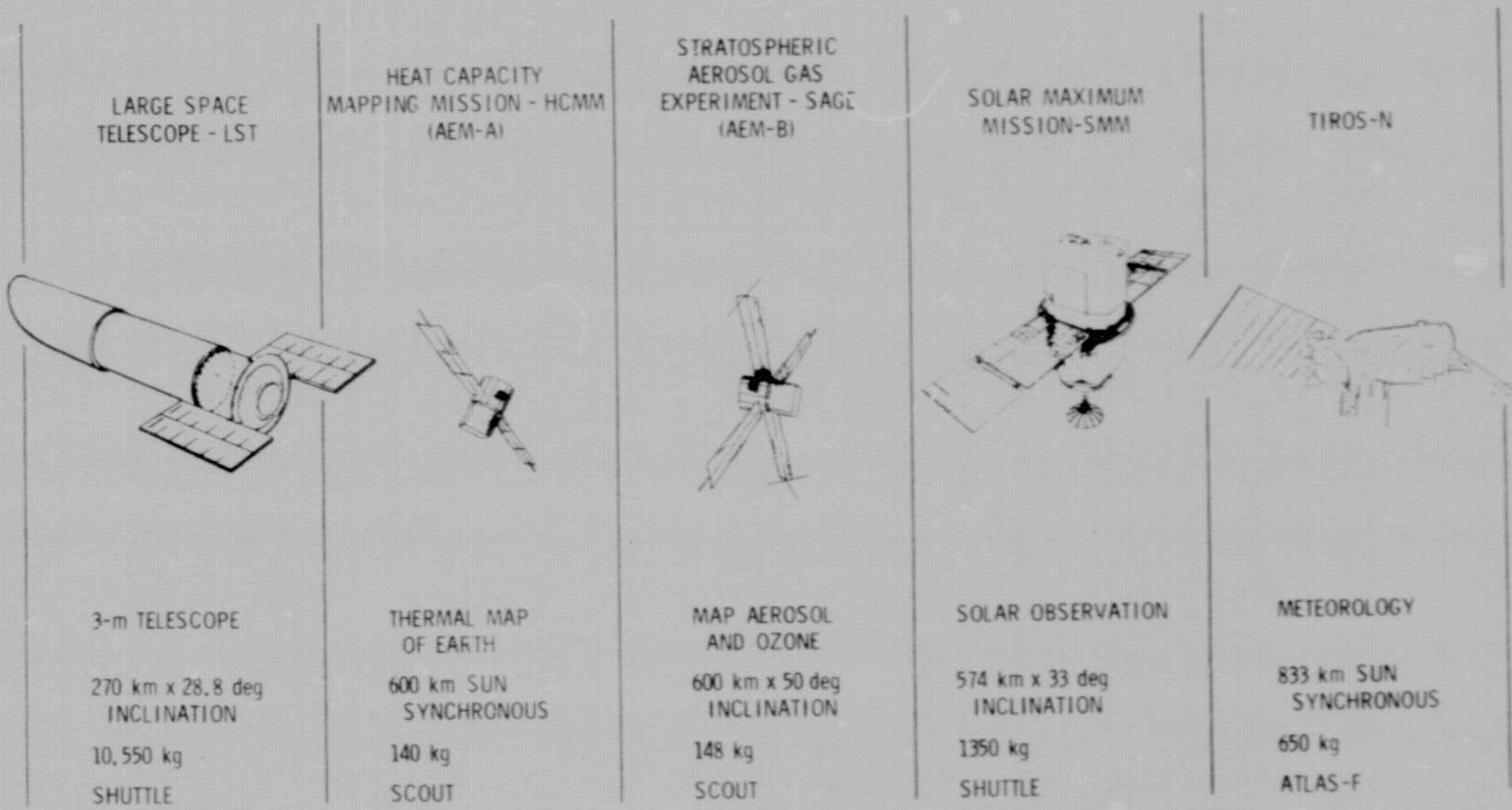


Figure 5-1. NASA New Starts Analyzed

usual" approach for four new starts. Most of the savings (76%) resulted from the reduction of component DDT&E costs. The unit spacecraft costs were also reduced, which represented 26% of the total savings.

The Equipment Compendium (catalog) provided up to 61% of the flight-qualified components. Of the selected components, 35% were DoD and 26% were NASA developed units. An additional 8% of the components were selected from other programs that were not cataloged. The NASA Standard Equipment represented only 3% which was understandably low because the study first searched the catalog for developed units before selecting a NASA standard. A higher percentage of NASA Standard Equipment could have been selected if the goal was to maximize the use of standard equipments. The balance of 28% to complete the housekeeping subsystems was new development hardware.

In addition to the extensive use of developed components, the study indicated that the modifications were relatively low. Over 70% of the flight-qualified components can be integrated with less than 10% development and 30% will require over 10% development.

The cost savings summarized in Table 5-1 is based on one flight unit and without mission equipment cost. The baseline cost savings is the difference between business-as-usual and extensive use of developed components. The alternate configuration represents a variant design by selecting other components. The total savings are for four new starts. The fifth new start studied was not included in the cost analysis since the spacecraft is a DoD spacecraft except for reconfiguring the communication for the NASA net.

The findings of the secondary task were that design-to-cost should be limited to programs where development is accomplished and the interfaces can be clearly defined at the start of contract. The design-to-

Table 5-1. Summary of Cost Savings

New Starts	DDT&E		Unit		Total	
	Savings $M	Percent Savings	Savings $M	Percent Savings	Savings $M	Percent Savings
LST						
Baseline	45.6	32	19.6	30	65.2	31
Alternate	50.9	36	29.2	44	80.1	39
HCMM						
Baseline	14.1	33	1.1	10	15.2	29
Alternate	14.6	35	1.2	11	15.8	30
SAGE						
Baseline	6.6	29	0.7	6	7.3	21
Alternate	7.7	33	0.6	5	8.3	24
SMM						
Baseline	17.3	25	4.6	21	21.9	24
Alternate	20.1	29	4.8	22	24.9	27
Baseline	83.6	30	26.0	17	109.6	26
Alternate	93.3	33	35.8	21	129.1	30

cost philosophy is most applicable to the production phase when practical cost trades can be made. The technical problems that may be encountered in an advanced spacecraft are difficult to quantify and control during the DDT&E phase.

6. STUDY OF THE COMMONALITY OF SPACE VEHICLE APPLICATIONS TO FUTURE NATIONAL NEEDS (STUDY 2.5)

The study identified over 100 new and highly capable space systems for the 1980-2000 time period, designed to enable large numbers of ordinary citizens to personally benefit from space in their everyday lives, as well as to provide unprecedented kinds and levels of service to industry, government, science, and a variety of military strategic and tactical operations. The system needs for space transportation, orbit support, and technology were derived, and those likely to be shared between NASA and the DoD in the time period identified.

The high leverage space technologies for the time period of interest were identified as very large antennas and optics, high power/energy, lasers, microelectronic data processors and sensing devices, and cyrogenic refrigerators. Guiding principles for application of this technology were presented, including emphasis on deliberately making satellites large, complex, and highly capable, which in turn will allow the user equipment to be tiny, cheap, and portable; allowing its proliferation to millions of users and providing services not otherwise possible, while simultaneously minimizing the total of satellite and user equipment cost. Other principles identified include the use of large but simple reflector satellites in low altitude orbit for multinational systems; extensive use of orbital assembly, servicing, resupply, and reuse; and an identification of the primary roles of man as assembly, test, initialization, servicing, modification, retirement, and reuse functions in the support of large complex satellites (in addition to research and exploration).

A new concept in self-adjusting phased arrays consisting of inde-

pendent coarsely stationkept sub-units, with adaptive phase control to achieve performance equivalent to that single-structure antenna without the structural rigidity and weight was conceived during the course of the study. The concept would allow antennas and optics of essentially unlimited size to be constructed in space, without the usual weight and alignment constraints, and would enhance the feasibility of the large, complex satellites called for in the study.

Over 40 civilian and 60 military space system concept "initiatives" were identified representing a catalog of space opportunities for personal, civic, industrial, government, international, scientific, and military applications. Many of these initiative concepts were conceived during this study, and most depend on bold forecasts of the likely advance of technology in the high leverage areas identified above. The results of first-order calculations on size, weight, cost, and performance of each initiative were documented, as were their needs for transportation, orbital support, and technology.

A set of 42 program plans for civilian and military activities was derived using six alternate world situation scenarios identified in the study, spanning the range from war to peace in the international environment, and a corresponding range of internal domestic environments. The supporting needs of each of these program plans for low earth orbit transportation, orbital transfer transportation, orbital assembly and servicing vehicles, orbital support facilities, and required technology were then derived.

The supporting needs of the group of initiative concepts taken as a whole were derived, in which it was shown that the majority of systems require only the Space Shuttle; orbital transfer vehicles such as the interim and full capability tugs and a solar-electric propulsion stage; automated or

manual orbital assembly and servicing stages; and orbital suppor facilities such as orbital assembly yards, warehouses, and research and test stations.

It was then shown that for all non-catastrophic world futures considered, most of the potential missions for the NASA and DoD in the time period share the above requirements, such that single development programs could be expected to yield dual use supporting hardware.

The study also concluded that the great range of civilian capabilities represented by all the system concepts identified, including the 100 initiatives and all the programs in the 1973 NASA Mission Model, could be acquired with an average space budget of less than five billion a year, provided that the peaks in funding can be properly phased or that some arrangement can be made to amortize the peaks.

A presentation summarizing the results of the study was briefed to most NASA Centers and Offices, the Administrator, the staff and some members of the House Subcommittee on Space Science and Application, the National Space Institute, and many others, including numerous military personnel. The messages have the potential of favorably impacting the way the public sees the National space program, and a vigorous public relations activity is recommended.

7. STS SPIN STABILIZED UPPER STAGE (SSUS) STUDY (STUDY 2.6)

The SSUS Study investigated the utility of spinning solid upper stages deployed from the Orbiter to perform a variety of upper stage NASA payload missions. The general concept of the SSUS is illustrated in Figure 7-1. The nominal geosynchronous mission began with Orbiter injection into a 296 km (160 nmi) parking orbit. The SSUS was elevated on the cradle/spin table in the Orbiter cargo bay, spin stabilized and separated. After separation to a safe distance the SSUS perigee motor was fired, injecting the spacecraft into a geosynchronous transfer orbit. The spacecraft was tracked by ground stations while in the transfer orbit and the spacecraft apogee motor fired to circularize the orbit at 35,786 km (19,323 nmi).

The SSUS was found to be more attractive for Delta class payloads (up to 1000 lb on orbit) and Atlas Centaur class payloads (up to 2100 lbs on orbit). The Delta class missions appeared particularly attractive due to the multiple payload possiblities. The SSUS was found to be most applicable to spin stabilized payloads and 3-axis stabilized payloads designed for spinning transfer missions, such as, RCA Satcom and Fleetsatcom. Large TIIIC, TIIIE/Centaur class payloads and complex 3-axis stabilized satellites such as the EO-09A Synchronous Earth Observation Satellite (featuring a 1.5 meter telescope sensor) could be flown with a SSUS system, but the satellite modifications were extensive and the SSUS system became essentially as large as an IUS.

The Task 2.6 study involved four subtasks; Subtask I was the NASA Geosynchronous Payload Model Development. NASA non-communication/navigation payloads were studied for SSUS deployment. SSPDA Tug

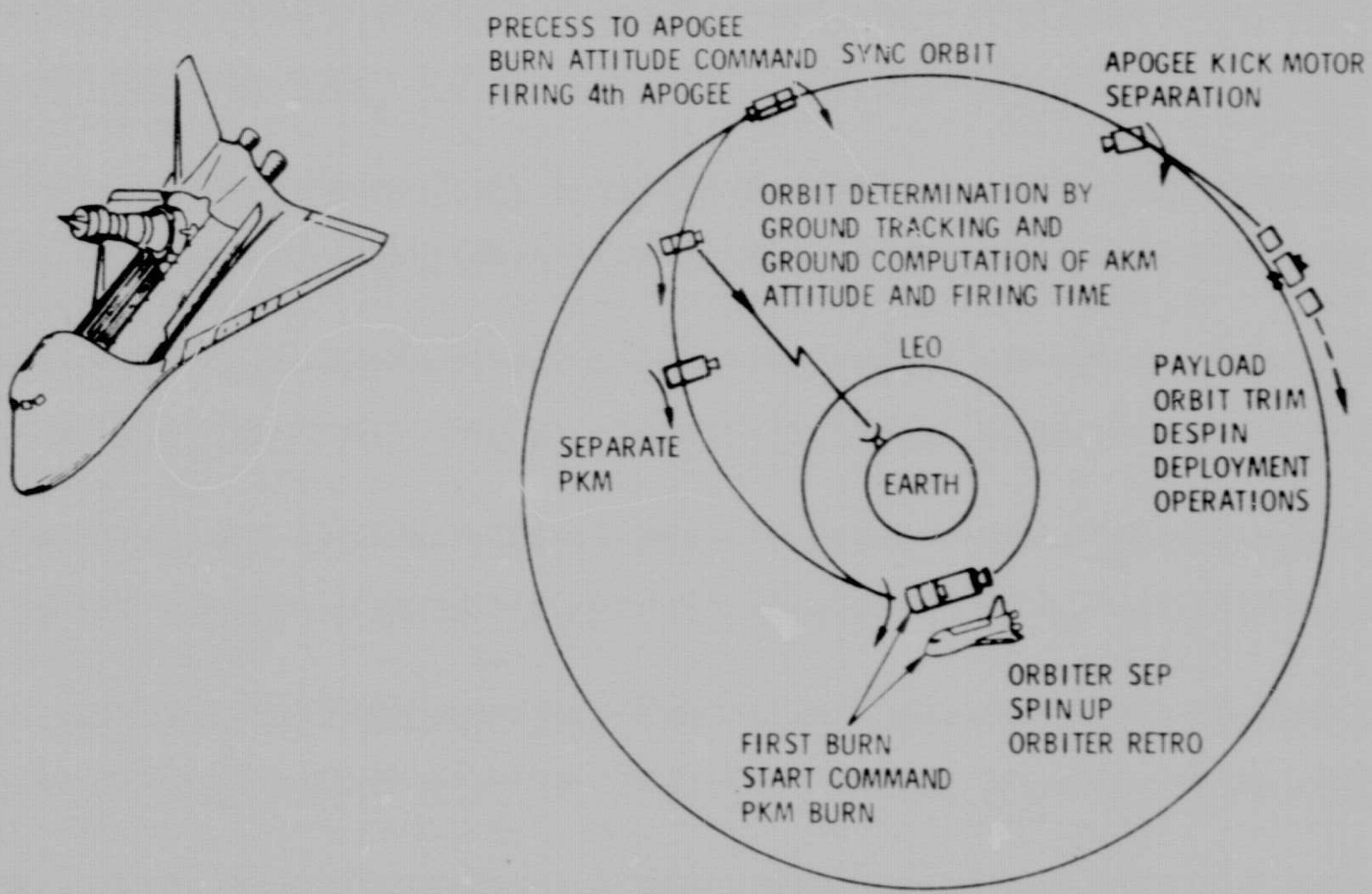


Figure 7-1. SSUS Geosynchronous Ascent Profile

design payloads were studied for the impact of SSUS. Spin stabilized satellites were found to be readily adaptable to SSUS. It was feasible to spin the 3-axis satellites for the SSUS deployment and to despin after apogee injection for normal 3-axis stabilized orbital operations. The satellite and SSUS combinations studied were unstable due to the low spin inertia to transverse inertia ratio through final injection so that an active nutation control was required. Partial power up from the folded solar revolutions prior to final injection to supply power for the active satellite/SSUS systems.

The 3-axis stabilized satellites required addition of sun and earth sensors, active nutation, some TT&C components and ACS propellants for nutation control, precession maneuvers, and injection error correction. Cost estimates of the satellite SSUS impacts were prepared using the FY 1974 NASW-2575 Study 2.3 System Cost/Performance Analyses, modified to use component data supplied by satellite subsystem specialists. The SSUS estimated cost impacts to spin stabilized satellites were negligible and, in fact, with small redesign the progenitor SMS/GOES satellites of today are compatible with the SSUS. The estimated cost impact to the larger 3-axis spacecraft ranged from $2 to $6M in the development costs and $0.5 to $1.5M in the unit costs.

Subtask II involved several SSUS study areas; geosynchronous mission sizing studies, accuracy, conceptual stage/cradle design, and SSUS system cost estimation. The Subtask II sizing studies were combined with Subtask III which is primarily a review of the total NASA 1981-1991 Mission Model for SSUS capture and recommendations on resizing. The sizing studies indicated that the entire geosynchronous mission model could be accomplished with two new solid rocket motors having about 1800 kg (4000 lb) and 6000 kg (13,250 lb) of propellant at their design points,

off-loaded versions of these motors, and existing TE-M-364 series and TE-M-616 motors (as shown in Table 7-1). These sizing studies were conducted on an optimum velocity propellant off-load basis for geosynchronous and earth orbit missions so as to provide minimum orbital errors. Energy management techniques with non-optimum velocity vectors and pitch/yaw angles introduce larger injection errors, but would reduce the number of solid rocket motor propellant loadings required. The planetary mission designs did not resolve issues of injection accuracy and orbit correction which were established to be solvable problems for earth orbit missions.

The injection accuracy studies utilized the Orbiter initial navigation position and capability to establish a state vector using an accurate payload mounted (spin table in the case of SSUS) auxiliary sensor (star sensor selected) as stipulated in JSC07700 Volume XIV. Other SSUS error sources and their magnitude were assessed in several areas of study. These studies included tip-off errors, attitude sensing and command errors, and dynamic errors. The overall evaluation of these errors showed the SSUS to be equal to the present day Delta 2914 expendable launch vehicle accuracy into the geosynchronous transfer orbit. Utilizing the same techniques of ground station tracking and command of the satellite in practice for today's Delta payloads, near-perfect final orbits are achievable by carrying about 45 meters per second (150 ft per second) of ACS propellant equivalent in the satellite. These errors are considerably greater than the estimated errors for the Tug and IUS and exceed the SSPDA satellite injection accuracy requirements (as shown in Table 7-2).

The conceptual design studies of the SSUS examined several ideas on SSUS deployment from the Orbiter, but settled on the Orbiter Bay cradle mounted spin table as the baseline concept most representative of the SSUS system type. The spin table provided the most direct deployment

Table 7-1. Solid Motor Characteristics for Geosynchronous Missions

	NM1	NM2	TE-364-4	TE-364-3	TE-M-616
Propellant Weights, kg (lb)	6012.9 (13.256)	1814.8 (4001)	1038.7 (2209)	653.2 (1440)	332.9 (734)
Motor Case Weight, kg (lb)	668.2 (1473)	201.8 (445)	83.0 (183)	64.9 (143)	29.5 (65)
Total Motor Weight, kg (lb)	6681.1 (14,729)	2016.7 (4446)	1121.8 (2473)	718.0 (1583)	362.4 (799)
Propellant I_{SP}, sec	292	292	286	290	293
Total Impulse, N-sec (lb-sec)	1.722×10^7 (3.871×10^6)	5.2×10^6 (1.168×10^6)	2.91×10^6 (654,400)	1.860×10^6 (418,100)	9.57×10^5 (215,200)
Thrust, N (lb)	143,448 (32,250)	61,138 (13,745)	68,490 (15,400)	43,146 (9700)	26,688 (6000)
Burn Time, sec	120	85	41	42	35
Propellant Mass Fraction	0.90	0.90	0.926	0.910	0.919

Table 7-2. Task II Geosynchronous Injection Accuracies

	Typical Satellite Requirement[1]	IUS[2]	TIIIC	EO-57A/SSUS	
				3	4
ΔV_T m/sec (ft/sec)	12.89 (42.3)	4.88 (16)	9.14 (30.0)	35.96 (118)	42.55 (139.6)
ΔV_R m/sec (ft/sec)	12.89 (42.3)	22.86 (75)	30.48 (100.0)	104.24 (342)	30.48 (100.0)
ΔV_N m/sec (ft/sec)	17.19 (56.4)	3.66 (12)	24.38 (80.0)	42.67 (140)	28.41 (93.4)
ΔP_T km (nmi)	46.3 (25)	122.2 (66)	148.2 (80.0)	135.2 (730)	N. A.[5]
ΔP_R km (nmi)	46.3 (25)	92.6 (50)	129.6 (70.0)	110.2 (595)	107.8 (582.2)
ΔP_N km (nmi)	62.0 (33.5)	74.1 (40)	83.3 (45.0)	759.3 (410)	9.26 (5.0)
ΔV (RSS) m/sec (ft/sec)	25.05 (82.2)	23.65 (77.6)	40.08 (131.5)	118.26 (388)	59.59 (195.5)
ΔV Relative to Satellite Requirement	0	(-1.40) (-4.6)	+14.93 (+49.0)	+93.26 (+306)	+34.44 (+113.0)

[1]SSPDA Data for EO-09A, EO-57A, and EO-07A

[2]SR-IUS-100

[3]Preliminary Data, February 1975, Start Task I w/o AKM Bias Correction

[4]Data, June 1975, with AKM Bias Correction

[5]Not applicable - Payload in 5.5 deg/day drift orbit 15.24 m/sec 50 ft/sec ΔV

mechanism approach in utilizing the Orbiter navigation and pointing capability, appeared to have the fewest unresolved error sources in tipoff and spin up, and could be assessed within the study limitations. Solid rocket motor and structural shell design was conventional with explosive bolt and captive spring separation systems similar to present ELV practice. The spin table designs featured D. C. torque motor drives through a V-belt system and a short stiff shaft mounted in angular contact ball bearings. A conical spin table extension interfaced with the SSUS aft skirt. The spin table carried no launch loads as these were taken up by conventional IUS cradle style trunions. The spin table was rotated and erected by a ball screw jack system with electric motor drive. Safety analyses suggested electric motor dynamic braking and a mechanical brake to despin the platform in case of abort as well as after normal SSUS separation. Failure to retract the spin table can be resolved through a design that clears the Orbiter Bay doors and/or is jettisonable with explosive bolts and RMS disposal.

The designs and operating concepts were analyzed for RDT&E and unit costs, utilizing the SAMSO IUS assessment cost data bank. The IUS data bank exists in very great detail and presented some problems in interpretation due to the contrasting lack of detail in the SSUS concepts. Table 7-3 summarizes these cost estimates. The Delta Class Perigee Stage Only $34.1M RDT&E breaks down as follows: $6.3M Stage development, $10.5M Cradle/Spin Table Development, $7.6M System Engineering and Management, $6.4 other costs, and $3.3M for Facilities. An Atlas Centaur Class Perigee Stage System added another $27.1M total above the Delta Class costs.

Subtask IV required an operations analysis of the IBM and Martin Marietta Corp. IUS/Tug studies in contrast with conceptual SSUS operations. SSUS basic operations concepts of a system that is satellite-

Table 7-3. SSUS Cost Summary

	Two Stage				Perigee Stage Only			
	Geosync. Family EO-09A, EO-07A AS-05A, EO-57A		Delta Class EO-57A Only		Geosync. Family EO-09A, EO-07A AS-05A, EO-57A		Delta Class EO-57A Only	
Satellite Controlled								
RDT&E	$65.8M		$35.8M		$61.3		$34.1M	
Units/Yr.	6/YR	12/YR	6/YR	12/YR	6/YR	12/YR	6/YR	12/YR
EO-09A	1.05	0.90	---	---	0.68	0.53	---	---
EO-07A	1.00	0.86	---	---	0.65	0.56	---	---
AS-05A	0.95	0.82	---	---	0.61	0.53	---	---
EO-57A	0.81	0.70	0.81	0.70	0.56	0.49	0.56	0.49
Autonomous AKM Avionics								
RDT&E	$86.9M		$52.0M		N/A		N/A	
Units/Yr	6/YR	12/YR	6/YR	12/YR				
EO-09A	2.62	2.27	---	---				
EO-07A	2.57	2.57	---	---				
AS-05A	2.52	2.19	---	---				
EO-57A	2.38	2.07	2.38	2.07				

COST FY 76 $M NO FEE - BASED ON DEVELOPMENT OF ALL MOTORS AND SPECIFIC OFF-LOADED MOTORS REQUIRED FOR EACH CASE

dependent and commanded by a satellite operations control center ground net system differ sharply from the relatively autonomous IUS/Tug concepts. Ground operations are characterized by simplicity and a single major SSUS spin balance, alignment, and assembly facility at the launch site. The spin facility dynamically balances the individual motors and satellites, performs a precise CG alignment and assembly/ checkout for each SSUS stack, and installs the SSUS in the deployment cradle and/or spin table. From this facility, it would be transported like any other upper stage. The SSUS considered as an addition to the IUS or Tug has no significant impact on the IBM IUS/Tug Orbital Operations and Mission Support Study. The SSUS impacts are primarily in the Orbiter Interface and Flight Operations, the Ground Tracking Network, and the Spacecraft Operations Control Center.

Major SSUS study conclusions were:

a. The SSUS is a technically feasible method of injecting satellites into earth orbits with the STS.

b. New satellites whether 3-axis or spin stabilized can be economically designed for spinning transfers.

c. Present Delta and Atlas Centaur geosynchronous mission satellites all have spinning transfer capability and can be flown on SSUS.

d. Injection accuracy of the SSUS is equivalent to present Delta accuracy and inferior to Atlas/Centaur, Titan IIIC, and IUS accuracy.

e. Planetary missions involving spin stabilization of multiple solid rocket motors require further study for mission design, accuracy, and stability.

8. TECHNOLOGY ASSESSMENT AND FORECAST (STUDY 2.7)

The purpose of this study was to provide to NASA technological and planning insight based on The Aerospace Corporation's familiarity with DoD space technology and programs, and in-house technology innovations. The scope of this study included an assessment and forecast of passive and active sensing space technology based on understanding and review of relevant developments by the DoD, and assembly of a catalog of high-leverage unexplored technological opportunities. The time frame considered was through the year 2000, with a nearer cutoff date applicable for forecasts in which visibility so far into the future was not possible.

8.1 TECHNOLOGY ASSESSMENT AND FORECAST

In this task, The Aerospace Corporation has assessed the current state-of-the-art in passive and active remote sensing from space, with application to sensing of terrestrial, airborne, and spaceborne man-made and natural objects. A preliminary forecast has been prepared for the optical and microwave technologies. Areas emphasized were those where limited information was available in the general literature, and where SAMSO experience and estimates did not clearly coincide with NASA's. The forecast assumed nominal DoD emphasis similar to that experienced in the recent past and current environment.

Generally speaking, most technology areas are expected to progress in an evolutionary fashion and to be able to support the projected DoD systems at the appropriate times. The technology advancements considered included the following:

a. Optical Sensing
   1. Infrared sensors
   2. Visible sensors
   3. Multispectral scanners

b. Microwave Radiometry
   1. Antennas
   2. High power transmitters
   3. Low noise receivers

The forecast included descriptions of the characterisiics and performance of components and potential systems. Although mission life or mean mission duration is a prime consideration in all SAMSO spaceborne equipment, no effort was made to quantify reliability here because the interdependence among parts of different space systems made it difficult to compare experience with specific components.

The forecast included a section showing the projected trends in performance according to year of availability. Trends were presented for the outstanding characteristics for each technology, system, and/or component. Specific data points taken from the system component material were identified in order to substantiate the projected trends.

8.2 NEW TECHNOLOGICAL OPPORTUNITIES

In the preparation of a list of possible space initiatives for the 1980 - 2000 period, a significant number of technology items were identified that merit further highlighting for possible future development. The technology items can be categorized as follows:

a. Lasers
b. Large structures
c. Observation technology
d. Quantum state engineering

Examples of these items include an adaptive self-pointing method for directing laser energy to a small distant target, a computer controlled phased array transmitting or receiving antenna for synthesizing high quality fronts from poorly postioned elements, and a very low noise level microwave detector. All these items are of a relatively advanced character, suited for consideration in advanced planning for the 1980 - 2000 period and unlikely to be currently included in present short-term development plans.

The items represent the following classes of items:

a. Ideas for specific devices potentially useful for advanced space systems: for example, a Mylar* film optical mirror whose figure can be controlled using electrostatic forces generated by locally sprayed charge.

b. Specific technology areas whose understanding will permit significant advances in space systems or in applications of current systems: for example, the technology applications of extremely low temperatures in the millikelvin range, or the mechanization of long life cyrogenic refrigerators with no moving parts for detector cooling using magnetic control of electron spin alignment in certain materials.

c. More speculative technology areas or device possibilities, which are not easy to concretely specify at present but which, on future exploration, may result in significant space applications: for example, uses of plasma phenomena to couple energy from one electromagnetic mode to another.

The Aerospace Corporation has performed the preliminary analyses to determine whether further exploratory work is worthwhile, systematized the description of the items, and documented the results in a brief technical summary with an accompanying diagram for each item. Approximately ten items have been treated in this preliminary fashion and assembled into a catalog.

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* Registered trademark